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(54) Title: FGF9 AS A SPECIFIC LIGAND FOR FGFR3

(57) Abstract

The present invention concerns fibroblast growth factor 9 (FGF9) as a high affinity ligand for fibroblast growth factor receptor 3 (FGFR3) which ligand is capable of binding and activating FGFR3 in a specific manner. The present invention is also directed to methods for detection of FGFR3 by utilizing FGF9, as well as to pharmaceutical compositions for modulating the activity of FGFR3 comprising as an active ingredient FGF9, antagonists thereof or FGF binding agents which are capable of neutralizing native circulating FGF9. The present invention further concerns novel recombinant mouse and chicken FGF9, expression vectors comprising these recombinant FGF9s and a transgenic animal transformed with said expression vectors.

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FGF9 AS A SPECIFIC LIGAND FOR FGFR3

FIELD OF THE INVENTION

The present invention concerns fibroblast growth factor 9 (FGF9), a novel high affinity ligand for fibroblast growth factor receptor 3 (FGFR3), methods for detecting FGFR3 using said ligand and pharmaceutical compositions for modulating FGFR3 activity comprising FGF9, an antagonist thereof, or FGF9 binding–agents.

BACKGROUND OF THE INVENTION

Fibroblast growth factors (FGF) comprise a family of at least nine multifunctional polypeptides involved in a variety of biological processes including morphogenesis, angiogenesis and tissue remodeling. They stimulate the proliferation of cells from mesenchymal to epithelial and neuroectodermal origin. FGFs share structural similarity, but differ in their target specificity and spatial and temporal expression pattern. Four FGF receptor (FGFR) genes encoding transmembrane protein tyrosine kinases, have been cloned and identified in mammals and their homologues described in birds, *Xenopus* and *Drosophila* (Givol and Yayon, *FASEB J.*, 6:33623369 (1992)). The actual number of functional receptor proteins is however much greater since multiple variants are generated, as cell bound or secreted forms, by alternative RNA splicing and multiple polyadenylation sites. Beside these high affinity receptors, FGFs bind tightly to low affinity, high capacity

binding sites identified as heparan sulfate proteoglycans (HSPGs). These heparan sulfates modulate FGF-receptor binding and biological activity and serve as an obligatory integral component in the formation of a functional tertiary complex between FGF, FGFR and the appropriate HSPG.

In light of the large number of ligand and receptor variants, a major question regarding FGF function is their ligand-receptor specificity. Both FGFR1 and FGFR2 bind acidic FGF/FGF1 and basic FGF/FGF2 with similar affinity (Dionne *et al., EMBO J.*, **9**:2685-2692 (1990)). In fact all FGFRs tested so far bind FGF1 and FGF4 (hst/kfgf) with moderate to high affinity, demonstrating an apparent redundancy in the FGF system. In contrast to FGFRs 1 and 2, FGFR3 was found to bind only FGF1 and FGF4 albeit with moderate affinity (Ornitz and Leder, *J. Biol Chem.*, **267**:16305-16311 (1992); Chellaiah *et al., J. Biol. Chem.*, **269**(15):11620-11622, (1994)). No specific ligand has been identified so far, for either of the spliced forms of this receptor.

Recently, mutations in FGFR3 have been shown to be responsible for achondroplasia, the most common form of genetic dwarfism. Examination of the sequence of FGFR3 in achondroplasia patients identified a mutation in the transmembrane domain of the receptor.

The focus of FGFR3 as the receptor involved in achondroplasia raised the need for a specific ligand for this receptor, which does not substantially bind to the other three FGFRs, both for the purpose of research and study of this disease as well as for the purpose of developing possible medicaments for its treatment.

A heparin-binding, glia-activating factor purified from the culture supernatant of a human glioma cell-line was found, by a homology search, to be the ninth member of the FGF family and was thus termed FGF9. Human FGF9 was found to code for a 208 amino acid protein and presents a unique spectrum of biological activity as it stimulates the proliferation of glial cells, PC-12 cells and BALB/C 3T3 fibroblasts, but nevertheless is not mitogenic for endothelial cells (Miyamote *et al., Mol. Cell. Biol.*, **13**(7):4251-4259 (1993); Naro *et al., J. Biol. Chem.*, **267**:16305-16311 (1993)).

SUMMARY OF THE INVENTION

The present invention is based on the surprising finding that fibroblast growth factor 9 (FGF9) is a high affinity (kD: 0.25 nM) ligand for fibroblast growth factor receptor 3 (FGFR3) which does not bind to FGFR1 or FGFR4 and binds to FGFR2 only at a substantially lower affinity.

Thus, the present invention provides for the first time a specific ligand for FGFR3 being a fibroblast growth factor 9 (FGF9). This specific FGFR3 ligand may be used both for detection and for therapeutical treatment purposes.

This specific novel ligand for FGFR3 may be used in a method for the detection of FGFR3 in a sample or tissue comprising:

(i) contacting the sample or tissue with FGF9 and allowing formation of receptor–ligand pairs, and

(ii) detecting the presence of FGFR3–FGF9 pairs, a positive detection indicating the presence of FGFR3 in the sample or tissue.

The sample may be a sample of body fluid such as blood, in which soluble FGFR3 is present and the tissue may be a tissue obtained from a patient, for example by cartilage biopsy or alternatively, may be a tissue within the body of an individual and in such a case the detection is carried out *in vivo*.

Detection may be carried out for example by labelling the FGF9 with a suitable detectable label, and then determining whether any label is bound to proteins in the sample or to the surface of cells in the tissue which is assayed for the presence of FGFR3. Alternatively detection may be carried out by using labeled antibodies against FGF9, capable of recognizing FGF9 which is bound to FGFR3.

In accordance with the present invention, it was found that FGF9 is a heparin–dependent ligand for FGFR3. Thus, in accordance with the method of detection of FGFR3 by use of the FGF9 ligand, it is preferable that heparin would also be present in the detection medium.

In accordance with the present invention, it was further found that FGF9 not only specifically binds to the FGFR3, but also specifically activates this receptor without activating the FGFR1 and FGFR4 receptors and, if appropriate concentrations are chosen, without significantly activating FGFR2. This finding leads to the preparation of pharmaceutical compositions comprising a pharmaceutically

acceptable carrier and as an active ingredient a therapeutically effective amount of FGF9. Such a pharmaceutical compositions may be used for stimulating the activity of FGFR3.

This finding also leads to the preparation of pharmaceutical compositions comprising a pharmaceutically acceptable carrier and as an active ingredient an antagonist of the FGF9, or an FGF9 binding agent an example being an antibody against FGF9.

Pharmaceutical compositions comprising an antagonist of FGF9 may be used to attenuate directly the activity of the FGFR3, and pharmaceutical compositions comprising an FGF9 binding agent such as an antibody against FGF9, may neutralize circulating native FGF9 and thus attenuate indirectly the activity of FGFR3.

Normal cartilage and bone growth and repair of damage to the cartilage and bone requires a specific and delicate balance between up regulation and down regulation of the activity of the FGFR3. Without wishing to be bound by theory, it is assumed that active FGFR3 is necessary in the initial stages of cartilage-bone differentiation, and after differentiation is required for cartilage-bone repair. Thus, the pharmaceutical composition comprising as an active ingredient FGF9, which stimulates the activity of FGFR3, may be used in order to encourage cartilage and bone repair, for example by administration to the site of injury. Furthermore, FGFR3 exists usually temporarily on mesenchymal stem cells and usually disappears after differentiation. Administration of FGF9 may serve to stabilize FGFR3 and thus prolong the period in which it is active prior to differentiation. FGF9 has also a chemotactic affect of FGFR3-carrying cells and can promote migration of such FGFR3 carrying cells, typically mesenchymal stem cells, to a desired site, for example, by injection of FGF9 to the growth plate top of the column.

According to this theory, overactivation of FGFR3 after the stage of initial differentiation of bone and cartilage cells, leads to halted growth, and is probably the cause of achondroplasia. Thus, a pharmaceutical composition comprising as an active ingredient an antagonist of FGF9 which attenuates the activity of FGFR3, or comprising an FGF9 binding agent (such as an antibody against FGF9), which neutralizes native circulating FGF9, should be used in cases

of overactivity of the FGFR3 receptor in differentiated tissues, which causes bone and cartilage growth arrest. Such bone and cartilage growth arrest may lead to achondroplasia dwarfism, or other abnormalities of bone and cartilage growth, for example, multiple hereditary exostosis, solitary hereditary exostosis, hallux valgus deformity, synovial chondromatosis and endochondromas.

The above conditions may be treated with a pharmaceutical composition comprising either an antagonist of FGF9, or an FGF9 binding agents capable of neutralizing native circulating FGF9, which both serve to attenuate the activity of the FGFR3.

The present invention also concerns a novel recombinant mouse FGF9, and a novel recombinant chicken FGF9, as well as DNA sequences coding for these novel recombinant proteins.

The present invention still further concerns an expression vector comprising the sequence of FGF9 under the expression control of a strong promoter such as the CMV or SV40 or a cartilage/bone promoter such as collagen type-2 promoter. Such an expression vector may be used to produce a transgenic mammal, which over-expresses FGF9, leading to overactivation of the FGFR3 receptor and thus to halted growth. Such an animal may serve as a model for diseases and disorders resulting from halted growth, such as genetic achondroplasia.

In the following the invention will be illustrated with reference to some non-limiting drawings and examples.

DETAILED DESCRIPTION OF THE DRAWINGS

Fig. 1 – Nucleotide and amino acid sequences of mouse FGF9. The nucleotide sequence of FGF9:pET-3C and deduced amino acid sequence are shown.

Fig. 2 – Nucleotide and amino acid sequences of chicken FGF9. The nucleotide sequence of FGF9:pET-3C and deduced amino acid sequence are shown.

Figs. 3A, 3B, 3C shows comparison of amino acid and nucleotide sequences of mouse, rat and human FGF9.

Fig. 4 – Purification of FGF9. Partially purified FGF9 was bound to heparin sepharose and eluted with a 0.2 – 2 M salt gradient, protein amount was estimated

by spectrophotometer (A). To identify FGF9 in the elution fractions, 10 ml of each fraction were resolved on 15% SDS PAGE, transferred to nitrocellulose and immunoblotted with specific antibodies (anti SP32) (B). The purity of the fractions was tested by silver staining of 5 ml of each fraction resolved on 15% SDS PAGE (C).

Fig. 5 – FGF9 binding specificity. Purified FGF9 was immobilized on heparin sepharose beads and its ability to bind the soluble extracellular domain of different FGFRs coupled to alkaline phosphatase was tested (A). The amounts of FGFRs were estimated according to alkaline phosphatase activity (B). Equal amounts of soluble extracellular domain of FGFRs 1, 2, 2-IIIb, 3, 3-IIIb and 4 alkaline phosphatase fusion proteins, were immunoprecipitated with anti alkaline phosphatase antibodies. Binding and cross-linking of ^{125}I-FGF9 in the presence or absence of 0.5 μg/ml heparin and hundred fold excess unlabeled FGF9 (Ex. cold) was done as described under materials and methods.

Fig. 6 – Analysis of FGF9 binding to soluble FGFR2 and FGFR3. Binding of increasing concentrations of ^{125}I-FGF9 to soluble extracellular domain of FGFR2 (A) and FGFR3 (B) adsorbed to maxisorb plate was done as described under materials and methods. Binding results were analyzed by Scatchard analysis (inserts).

Fig. 7 – Heparin dependent cross-linking of FGF9 to FGFR3 expressing CHO cells. Monolayers of FGFR3 transfected KI and A745 CHO cells were incubated at 40°C with 5 ng/ml ^{125}I-FGF9 in the presence or absence of 1 mg/ml heparin and 100-fold excess of unlabeled FGF9 (Ex. cold) as indicated. Cross-linking and electrophoresis separation were done as described under materials and methods.

Fig. 8 – Heparin and heparin fragments dependent FGF9 induced DNA synthesis. Monolayers of FGFR3 transfected CHO-A745 cells were serum starved and incubated with 10 ng/ml FGF9 and the indicated amount of heparin (A) or 2 mg/ml of heparin fragment (B) at the indicated number of monosaccharide units.

Fig. 9 – Plasmid of FGF9 under control of collagen type-2 promoter.

DETAILED DESCRIPTION OF THE INVENTION

I. MATERIALS AND METHODS

(a) Cells.

Wild type (KI) and the CHO mutant cell line A745 kindly provided by Dr. J.D. Esko (Dept. of Biochemistry, University of Birmingham, Alabama) were cultured in F12 medium supplemented with 10% Fetal Calf Serum. Transfection of CHO cells with 10 μg FGFR3 in pZL plasmid that contain neomycin resistance, was done by electroporation with Gene Pulcer (Bio-Rad) at 960 micro farads and 250 volt. Individual stable clones were selected with G418 (0.5 mg/ml).

(b) Antibodies

Polyclonal anti FGF9 antibodies were generated by injecting New Zealand white rabbits and collecting serum after two additional boosts. Anti FGF9 antibodies were prepared against two peptides (SP31: Cys-Ser-Asn-Leu-Tyr-Lys-His-Val-Gln-Thr-Gly-Arg-Arg-Tyr, SP32: Asp-His-Leu-Lys-Gly-Ile-Leu-Arg-Arg-Arg-Gln-Leu-Tyr-Cys) coupled to KLH (keyhole lympet hemocyanin) by MBS. Serum obtained was further purified on protein A sepharose (Repligen) to obtain the IgG fraction.

(c) Radiolabeling of FGF9

Recombinant murine FGF9 was labeled with $Na^{125}I$(0.5mCi) using the Chloramine-T method and separated from free iodine on a heparin-sepharose column. The range of specific activity was 0.5-2 x 10^5 cpm/ng.

EXAMPLE 1: Cloning and expression of the mouse homologue of FGF9

Total RNA extracted from a 12.5 day old mouse embryo was used for polymerase chain reaction (PCR) based cloning of FGF9. Primer specific for the human FGF9 (forward: GGGAATTCCATATGGCTCCCTTAGGTGAAG; backward: CGGGATCCTCAACTTTGGCTTAGAATATCC) were used for PCR using as a template mouse RNA. (35 cycles of denaturation 1 min at 94°C, annealing 2 min at 56°C, elongation 3 min at 72°C). A single DNA product with an expected size of 630 bp was obtained and was used directly for subcloning into pET-3C bacterial expression vector (Novagene).

Sequence analysis reveals the expected 627 bp long transcript (Fig. 1) with 93% identity to the human FGF9 cDNA. The FGF9:pET-3C plasmid was used to transform B1-21 strain of *E. coli*. At logarithmic growth phase the transformed bacteria were induced with 1 mM IPTG for 2 hours, precipitated by centrifugation at 7000 RPM and sonicated 3x15'' using probe sonicator (Soniprep150, MSE) on ice. The supernatant obtained by centrifugation of the bacterial sonicate was loaded onto a heparin-sepharose column (Pharmacia, Upsala, Sweden) and the column was washed extensively with 10 column volumes of 0.15 M NaCl, 0.05% Chaps, 20 mM Tris pH 7.4, and 10 column volumes of 0.7 M NaCl, 0.05% Chaps, 20 mM Tris pH 7.4. The bound proteins were then eluted with 0.5 ml fractions of 2 M NaCl, 0.05% Chaps, 10 mM Tris pH 7.4, diluted 1:10 with H_2O and reloaded on a pre-equilibrated 1 ml heparin-sepharose mini FPLC column (Pharmacia, Upsala, Sweden). After extensive wash the column was eluted with a continuous 0.2 - 2 M NaCl gradient and the protein profile determined by adsorbance at 280 nM. The fractions were tested for biological activity measured as 3H-thymidine incorporation into BALB/c-3T3 fibroblasts and for specificity by Western blot using polyclonal antibodies generated in rabbits against FGF9 specific peptides. A major protein band at the expected molecular weight of 27 kDal was obtained that reacted specifically with two different anti-peptide antibodies specific for FGF9.

Mouse FGF9 (mFGF9) was cloned by PCR on cDNA prepared from 12.5 days mouse embryos RNA. Mouse FGF9 cDNA shares 93 and 98% sequence homology with human and rat FGF9 respectively (Figs. 3A-3C). The amino acid sequence of mFGF9 is identical to that of the rat FGF9 and differs from human FGF9 in one amino acid only having a serine at position 9 instead of an asparagine. Recombinant mouse-FGF9 was expressed in B1-21 strain of *E. coli* and purified from the bacteria lysate by two cycles on a heparin-sepharose column. FGF9 elutes from heparin sepharose with 1.0-1.2 M NaCl as determined by adsorbance at 280 nM (Fig. 4A). The presence of FGF9 in the fractions was tested by an immunoblot using polyclonal antibodies directed against FGF9 specific peptides, demonstrating a major protein band at the expected molecular weight for a non-glycosylated protein of 27 kDal (Fig. 4B). The purity of each preparation was

further assessed by silver stain (Fig. 4C). Recombinant mouse FGF9 is biologically active and stimulates DNA synthesis in BALB/C 3T3 fibroblasts, in a dose dependent manner, with half maximal 3H-Thymidine incorporation at 0.5 ng/ml (not shown), similar to that obtained for purified human FGF9 (Nauro, *et al., J. Biol. Chem.*, 267:16305-16311 (1993)).

EXAMPLE 2: Cloning and expression of the chicken homologue of FGF9

Cloning and expression of chicken homologue of FGF9 was conducted as described in Example 1 with chicken-derived mRNA.

EXAMPLE 3: Cell free binding assays

The extracellular region of murine FGFR1, FGFR2, keratinocyte growth factor receptor (KGFR) and the two isoforms of FGFR3 in the alkaline phosphatase-expression vector were previously described (Givol D. and Yayon A., Adv. Cancer Res. **160**, 1-41 (1993); (Lev *et al*, J. Biol. Chem., **267**, 15970-15977 (1992)). FGFR-alkaline phosphatase fusion proteins were collected from conditioned medium of transfected NIH 3T3 cells and used directly for binding assays. Receptor protein content was estimated by alkaline phosphatase activity which was monitored spectrophotometrically at 405 nm using para-nitrophenyl phosphate as a substrate, essentially as described (Lev *et al., supra*). The soluble receptor binding reaction mixture included receptor-AP conditioned medium, radiolabeled ligand and heparin or other HSPGs. The bound complex was immunoprecipitated with anti-alkaline phosphatase polyclonal antibodies (Zymed) and protein A-Sepharose (Repligen). All components are mixed at room temperature in a total volume of 250 ml of binding buffer (DMEM supplemented with 25 mM Hepes pH 7.4 and 0.1% bovine serum albumin). The binding reaction was allowed to proceed for 2 h at room temperature. Bound ligand was recovered by centrifuging for 10s at 6000 rpm in a microcentrifuge (~2000g) and washing three times with a solution of 150 nM NaCl, 0.1% Triton-X-100 and 50 mM Hepes pH 7.4 (HNTG). ^{125}I-bound factor was determined by counting the tubes directly in a gamma-counter. For cross-linking, after washing 0.15 mM disuccinimidyl suberate (DSS) or 1 mM Bis (sulfosuccinimidyl)suberate (BS3) was added in

phosphate buffered saline (PBS) for 30 min at room temperature. The complexes were washed twice with PBS, and boiled for 5 min with sample buffer. The samples were separated by electroporation under reducing conditions on SDS-polyacrylamide gel, the gel was dried and exposed to Kodak (Eastman Kodak Co., Rochester, NY) X-Omat AR film.

Alternatively, 96-well maxisorb plates (Nunk) pre-coated overnight with monoclonal anti-human placental alkaline phosphatase antibodies (Sigma Chemicals, Israel) were reacted with receptor-AP fusion proteins for 2 h at room temperature. After washing with binding buffer, plates were incubated for 2 h at room temperature with different concentrations of ^{125}I-labeled FGF9 in the presence or absence of heparin. At the end of the incubation time, the plates were washed twice with binding buffer, and eluted with 1.6 M NaCl in 20 mM sodium acetate pH 4.5. The acid extract was counted in a gamma counter.

In order to elucidate the receptor binding properties of FGF9, use was made of a series of FGF receptors' ectodomains coupled to human placental alkaline phosphatase. As was previously demonstrated, soluble ectodomains of FGF receptors can successfully and specifically interact with the ligands, thereby providing an excellent tool for the analysis of ligand-receptor specificity (Rimion, D.L, Prof. Clin. Biol. Res. **187**, 131-140 (1985), Lev *et al*, *supra*). The interaction between FGF9 and the soluble receptors was first analyzed with FGF9 immobilized on heparin-sepharose and measurement of the associated alkaline phosphatase activity. Heparin-sepharose immobilized FGF9 binds FGFR2 and FGFR3 fusion proteins but not FGFR1 or FGFR4 (Fig. 5A). Only the IIIc isoforms of FGFR2 and FGFR3 bind FGF9, while the IIIb isoforms of these receptors do not show any specific binding to FGF9. The interaction of FGF9 with the soluble receptors was further analyzed by direct binding and covalent cross-linking of radiolabeled FGF9 (Fig. 5B). In the presence of 0.5 mg/ml heparin, FGF9 binds only to FGFR2 and FGFR3 but not to FGFR1 or FGFR4 and not to any of the IIIb spliced isoforms tested. No significant binding is observed without heparin, indicating its obligatory role in high affinity FGF9- receptor binding. The two covalently linked complexes of FGF9 with FGFR2 and FGFR3 correspond most probably to the monomer and dimer forms of the receptor-ligand complex. Affinity labeling of soluble FGFR2

and FGFR3 proteins by ^{125}I-FGF9 is abolished in the presence of a 100 fold molar excess of unlabeled ligand, indicating that binding and labeling of these receptors is specific.

To quantitatively characterize the binding of FGF9 to FGFR2 and FGFR3, direct binding analysis of radiolabeled FGF9 to the soluble receptors was performed. Binding of FGF9 to both receptors is specific and saturable (Figs. 6A and 6B). Analyzing the results by Scatchard analysis (Fig. 6, inserts) indicate a dissociation constant of 2.38 nM for binding of FGFR2 and 0.78 nM for the interaction of FGF9 with FGFR3. Two additional experiments yield very similar results. Within every single experiment the affinity for FGFR2 was about 3-fold lower compared to that for FGFR3. The binding of FGF9 to FGFR1 was neither significant nor specific (not shown).

EXAMPLE 4 High affinity binding and cross-linking of FGF9 to cell surface receptors

Confluent cultures in 24 wells dishes (Nunk) were pre-cooled to 4°C and washed twice with binding buffer. Subsequently they were incubated for 2 h at 4°C with different concentrations of ^{125}I-FGF9 in binding buffer in the presence or absence of heparin. The binding medium was discarded, and the cells were washed twice with binding buffer and once with 0.5 M NaCl in 25 mM Hepes pH 7.5. High affinity bound factor was determined by eluting the bound factor with 1.6 M NaCl in 20 mM sodium acetate pH 4.5 and counting in a gamma counter. Nonspecific binding was considered as the value obtained for high affinity binding in the presence of a 100-fold excess of non-labeled factor. For cross-linking, the binding was done in PBS and after 1 h incubation, DSS was added to a final concentration of 0.15 M for 1 h more. The cells were washed twice with PBS, scraped, and lysed in a small volume of lysis buffer containing 150 mM NaCl, 20 mM Tris (pH 8.0), 1 mM $MgCl_2$, 0.1 mM $ZnCl_2$, 0.5% NP-40, 1 mg of aprotinin, 1 mg/ml leupeptin, and 2 mM PMSF. The cell lysates, clarified by centrifugation, were boiled and electrophorated under reducing conditions on SDS-polyacrylamide gel.

As mentioned above, the binding of FGF9 to both FGFR2 and FGFR3 is strictly dependent on the presence of heparin. To compare the specific demands for heparin in FGF9 binding to each receptor, we first measured the heparin required for binding of FGF9 to soluble FGFR3 and FGFR2. In cross-linking experiments only faint complexes are observed without the addition of heparin to either FGFR2 or FGFR3. However, at increasing heparin concentrations a marked difference in the requirement for heparin the two receptors is observed.

The soluble extracellular domains of FGFR2 and FGFR3 coupled to alkaline phosphatase, were immunoprecipitated with anti-alkaline phosphatase antibodies, and incubated with 5 ng/ml ^{125}I-FGF9 and increasing concentrations of heparin. Cross-linking and electrophoresis separation were done as described under Example 3. The amount of FGF9 bound to FGFR2 (Fig. 5A) and FGFR3 (Fig. 5B) was quantitated by densitometry analysis.

Binding of FGF9 to FGFR2 is very sensitive to heparin and addition of as little as 0.5 ng/ml heparin causes an apparent increase in binding, with maximal receptor binding at around 5 ng/ml. Binding of FGF9 to FGFR3 however, requires about 20-fold higher levels of free heparin, with maximal receptor binding only at around 100 ng/ml heparin, and with a slight inhibition of binding at heparin concentrations above 500 ng/ml.

A difference in the heparin levels required for FGF9 binding to either FGFR2 or FGFR3, might indicate that a more specific heparin structure, which comprises a relatively minor fraction of the heparin mixture which was used, is required for FGFR3 binding. To study structural requirements of heparin for promoting FGF9 binding, we analyzed the effects of a series of heparin fragments ranging in size from 4 to 18 monosaccharide units, on FGF9 binding to the soluble ectodomains of FGFR2 and FGFR3.

In order to address the physiological relevance of the *in vitro* observed high affinity, heparin-dependent interaction of FGF9 with FGFR3, a full length mouse FGFR3 was expressed in wild type (KI) and heparan-sulfate deficient mutant (745pgs) CHO cells, known to express low levels of endogenous FGFRs (Yayon, A., *et al.*, *Cell*, **64**:841-848 (1991). Whereas untransfected cells displayed neither detectable binding of radiolabeled FGF9 nor covalently cross-linked

proteins, FGFR3 transfected CHO-KI cells show a protein band of a 145 kDal, corresponding to a monomer of receptor-FGF9 complex (Fig. 7). As expected, binding and cross-linking of ^{125}I- FGF9 to wild type CHO-KI cells expressing FGFR3 is not affected by exogenous heparin. There is however no detectably, cross-linking of FGF9 to the mutant HS defficient CHO-745 cells expressing FGFR3 in the absence of heparin (Fig. 7), supporting the notion that heparin-like molecules are required for efficient high affinity interaction of FGF9. Upon the addition of heparin affinity labeling of the 745-FGFR3 cells with ^{125}I-FGF9 is prominent and indistinguishable from that of wild type cells, indicating that heparin can support high affinity binding of FGF9 to FGFR3. The binding to both kinds of cells was specific and saturable (in the presence of 1 mg/ml heparin) with kD of 0.06 and 0.1 nM for CHO-KI and CHO 745 cells respectively. A typical heparin dose dependent increase in FGF9 binding to CHO 745-FGFR3 transfected cells was obtained, with maximal specific binding at around 500 ng/ml of heparin (data not shown).

EXAMPLE 5 DNA synthesis assay

Thymidine incorporation into CHO cells was measured using confluent cultures grown in 24 well plates, in F12 medium supplemented with 10% fetal calf serum. The cells were starved for 24 h with no serum and then incubated with or without various concentrations of FGF9 or 10% serum as a control for an additional 14 h, after which 3H-Thymidine (0.5 mCi/ml) was added for additional 2 h. At the end of the incubation, the cells were washed twice with cold PBS, fixed for 20 min with ice-cold 5% trichloroacetic acid, washed with 95% ethanol and dissolved in 0.1 M NaOH. DNA associated radioactivity was measured by liquid scintillation counting.

To test whether activation of FGFR3 may also require heparin, we investigated the requirement for heparin for FGF9 induced DNA synthesis in FGFR3 expressing HS-defficient CHO 745 cells. Without exogenous heparin no significant increase in 3H-Thymidine incorporation by FGF9 is observed (Fig. 8A), in agreement with the lack of receptor binding and similar to the strict heparin requirement for other FGFs investigated so far. Addition of heparin at low

concentrations markedly stimulated FGF9 dependent DNA synthesis and in a dose dependent manner with half maximal and maximal effects at 100 ng/ml and 2 mg/ml respectively. Heparin alone had no effect on DNA synthesis and FGF9 induced DNA synthesis in CHO-KI is independent of exogenous heparin (not shown).

To study structural requirements of heparin for promoting FGF9 binding, we analyzed the effects of a series of heparin fragments ranging in size from 6 to 18 monosaccharide units, on FGF9 induced DNA synthesis. While a 6 mer heparin fragment inhibited the effect of FGF9, induction of DNA synthesis is observed with 8-10 mer fragments with maximal effect of FGF9 in the presence of 14-16 mer heparin fragments (Fig. 8B). These results indicate that a specific heparin size is required for activation of FGFR3 by FGF9.

EXAMPLE 6 Plasmid construct for the expression of FGF9

For the expression of recombinant FGF9, the mouse FGF9 cDNA was sub-cloned using the NdeI/BamH sites of the bacterial expression vector pET-3C. After transformation of BL-21 cells and induction with 1mM of IPTG, the cells were lysed and FGF9 was purified on a heparin-sepharose column.

Full length mouse FGF9 cDNA was subcloned downstream of a splice acceptor site from the collagen IIA1 gene following the collagen IIA1 promoter and cartilage specific enhancer. This construct was linearized and used for injection into fertilized mice eggs for the generation of transgenic mice.

EXAMPLE 7 Transgenic animal with over expression of FGF9

Transgenic mice transformed by the vector as described above feature an over-expression of FGF9. The phenotype of these transgenic mice is very similar to that of transgenic mice with FGFR3-Ach mutation (having the FGFR3 mutation of achondroplasia) characterized by an exceptionally small body size with a short tail and short hindlimbs. Such transgenic mice may serve as a model for various types of dwarfism as well as a model for abnormalities resulting from an excess of FGF9.

CLAIMS:

1. A method for the detection of fibroblast growth factor receptor 3 (FGFR3) in a sample or tissue comprising:

(i) contacting the sample or tissue with fibroblast growth factor 9 (FGF9) and allowing formation of receptor-ligand pairs; and

(ii) detecting the presence of FGFR3-FGF9 pairs, a positive detection indicating the presence of FGFR3 in the sample or tissue.

2. A method according to Claim 1, wherein the contact of sample or tissue with FGF9 is carried out in the presence of heparin.

3. A pharmaceutical composition for modulating of the activity of FGFR3 comprising a pharmaceutically acceptable carrier and as an active ingredient a therapeutically effective amount of FGF9.

4. A pharmaceutical composition according to Claim 3 for increasing the activity of FGFR3.

5. A pharmaceutical composition according to Claim 4 for stimulating bone and cartilage repair.

6. A pharmaceutical composition for modulating of the activity of FGFR3 comprising a pharmaceutically acceptable carrier and as an active ingredient an antagonist of FGF9, or an FGF9 binding agent.

7. A pharmaceutical composition according to Claim 6, wherein the FGF9 binding agent is an antibody against FGF9.

8. A pharmaceutical composition according to Claim 6 or 7 for decreasing the activity of FGFR3.

9. A pharmaceutical composition according to Claim 8 for the treatment of a disease or a disorder selected from the group consisting of:

multiple or solitary hereditary exostosis, hallux vagus deformity, achondroplasia, synovial chondromatosis and endochondromas.

10. A recombinant mouse FGF9 DNA having the nucleic acid sequence as depicted in Fig. 1.

11. A recombinant chicken FGF9 DNA having the nucleic acid sequence as depicted in Fig. 2.

12. A polypeptide comprising an amino acid sequence encoded by the recombinant mouse FGF9 DNA of Claim 10.

13. A polypeptide comprising an amino acid sequence encoded by the recombinant chicken FGF9 DNA of Claim 11.

14. An expression vector comprising the recombinant mouse FGF9 DNA sequence of Claim 10 or the recombinant chicken FGF9 DNA sequence of Claim 11 under the expression control of a strong promoter and/or a cartilage/bone tissue specific promoter.

15. An expression vector according to Claim 14, wherein the promoter is collagen type-2 promoter.

16. A transgenic animal transfected with an expression vector according to Claim 14 or 15.

17. A method for the stimulation of cartilage or bone repair comprising:

administering to the site of desired repair a therapeutically effective amount of FGF9, optionally together with a pharmaceutically acceptable carrier.

18. A method for the therapeutical treatment of a disease or disorder caused by an excess of FGF9 or over activity of FGFR3 comprising:

administering to a subject in need of such treatment a therapeutically effective amount of a FGF9-binding agent or an antagonist of FGF9.

19. A method according to Claim 18, wherein the FGF9-binding agent is an antibody against FGF9.

20. A method according to Claim 18 or 19, wherein the disease or disorder is selected from the group consisting of:

multiple or solitary hereditary exostosis, hallux vagus deformity, achondroplasia, synovial chondromatosis and endochondromas.

```
1    ACAACGGTTTCCCTCTAGAAATAATTTTGTTTAACTTTAAGAAGGAGATATACATATCGC
                                                          M  A

61   TCCCTTAGGTGAAGTTGGGAGCTATTTCGGTGTGCAGGACGCGGTACCGTTCGGGAACGT
       P  L  G  E  V  G  S  Y  Y  F  G  V  Q  D  A  V  P  F  G  N  V

121  ACCGGTGTTGCCGGTGGACAGTCCGGTGTTGCTAAGTGACCACCTGGGTCAGTCCGAAGC
       P  V  L  P  V  D  S  P  V  L  L  S  D  H  L  G  Q  S  E  A

181  AGGGGGGCTGCCCCCGGGGCCCCGCAGTCACGGACTTGGATCATTTAAAGGGGATTCTCAG
       G  G  L  P  R  G  P  A  V  T  D  L  D  H  L  K  G  I  L  R

241  GCGGAGGCAGCTGTACTGCAGGACTGGATTTCATTTAGAGATCTTCCCCAACGGTACTAT
       R  R  Q  L  Y  C  R  T  G  F  H  L  E  I  F  P  N  G  T  I

301  CCAGGGAACCAGGAAGACCACAGCCGCTTCGGCATTCTGGAATTTATCAGTATAGCAGT
       Q  G  T  R  K  D  H  S  R  F  G  I  L  E  F  I  S  I  A  V

361  GGGCCTGGTCAGCATTCGCGGTGTGGACAGTGGACTCTACCTCGGCATGAACGAGAAGGG
       G  L  V  S  I  R  G  V  D  S  G  L  Y  L  G  M  N  E  K  G

421  GGAGCTGTATGGATCAGAAAAACTAACACAGGAATGTGTGTTCAGAGAACAGTTTGAAGA
       E  L  Y  G  S  E  K  L  T  Q  E  C  V  F  R  E  Q  F  E  E

481  GAACTGGTACAACACCTACTCTTCCAACCTCTATAAACATGTGGACACCGGAAGGAGATA
       N  W  Y  N  T  Y  S  S  N  L  Y  K  H  V  D  T  G  R  R  Y

541  CTATGTTGCATTAAATAAGGACGGGACTCCAAGAGAAGGGACCAGGACTAAACGGCACCA
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601  GAAATTTACACATTTTTACCTAGACCAGTGGACCCTGACAAAGTACCTGAACTATATAA
       K  F  T  H  F  L  P  R  P  V  D  P  D  K  V  P  E  L  Y  K

661  GGATATTCTAAGCCAAAGTTGA  682
       D  I  L  S  Q  S  *
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Fig. 1

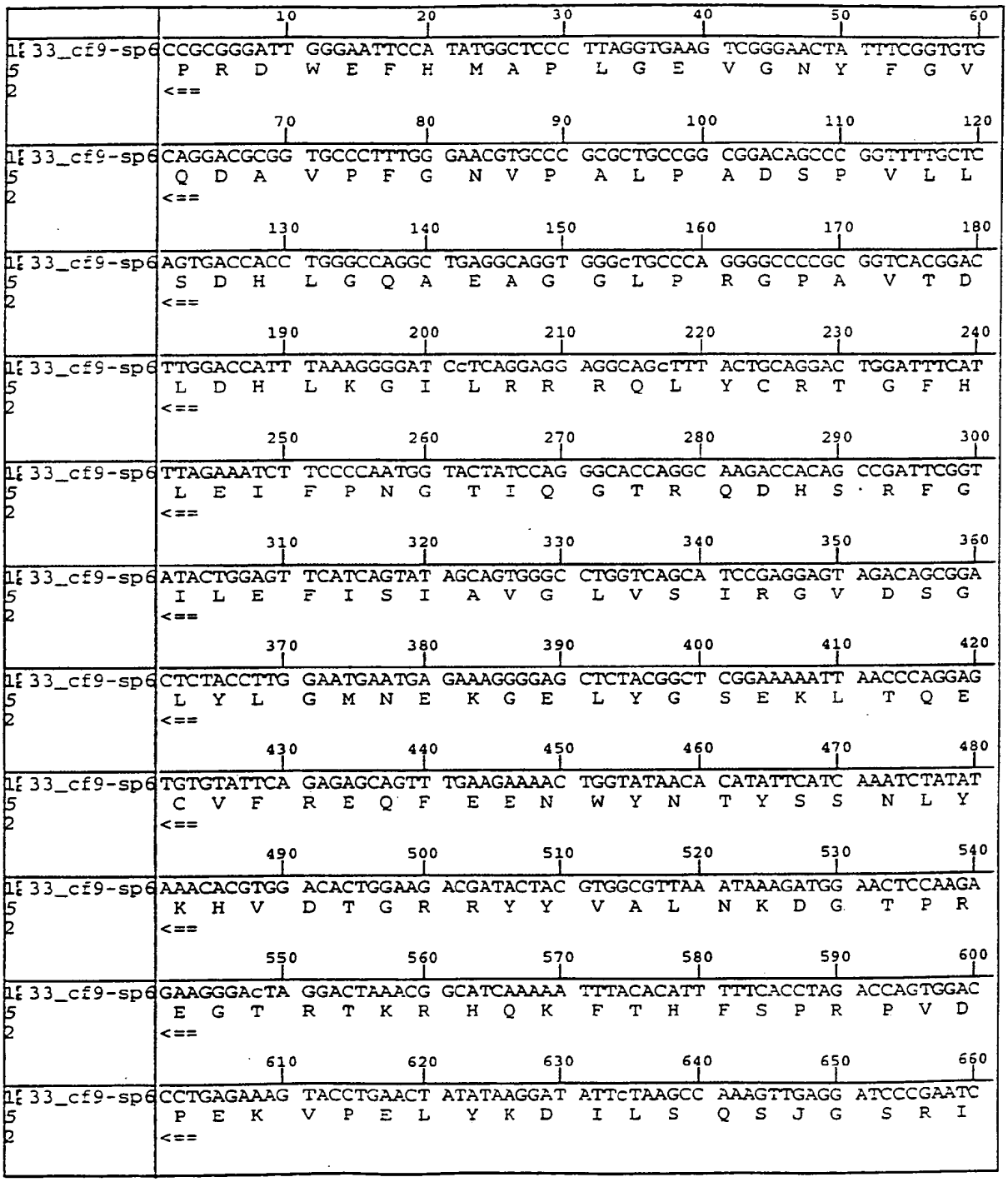

Fig. 2

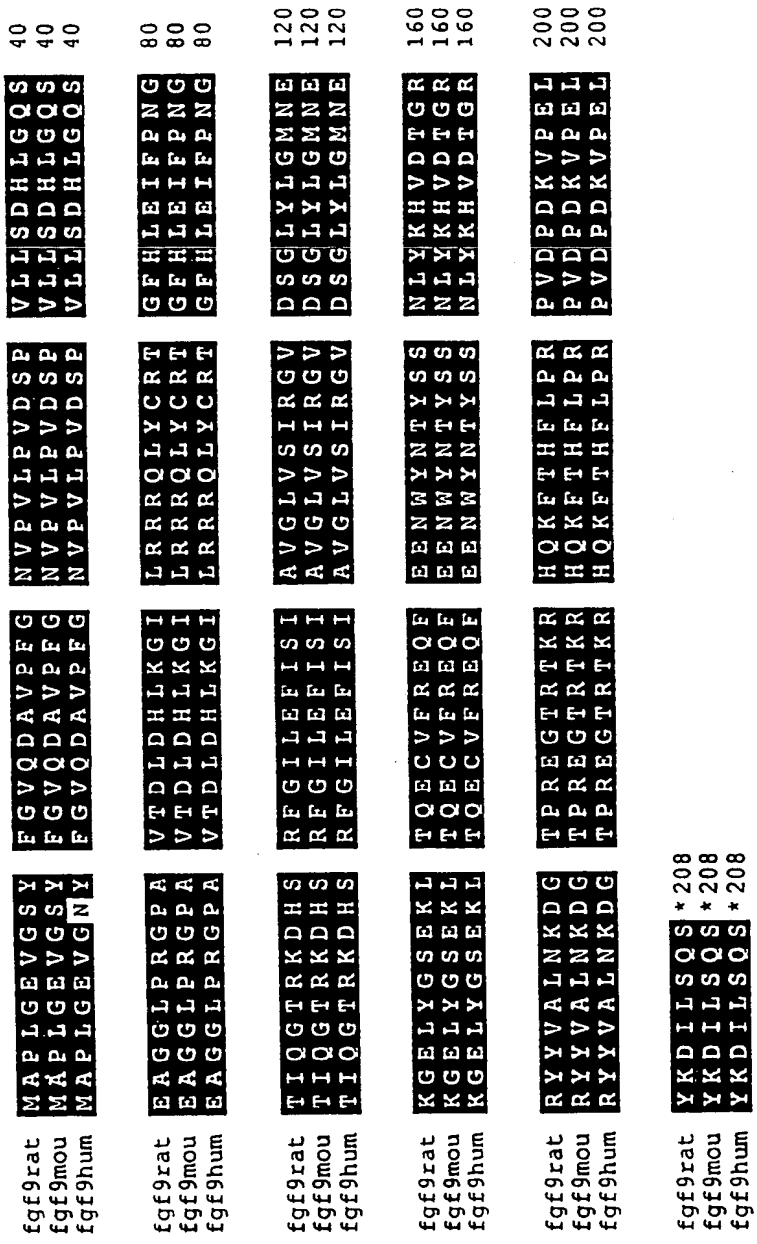

Fig. 3A

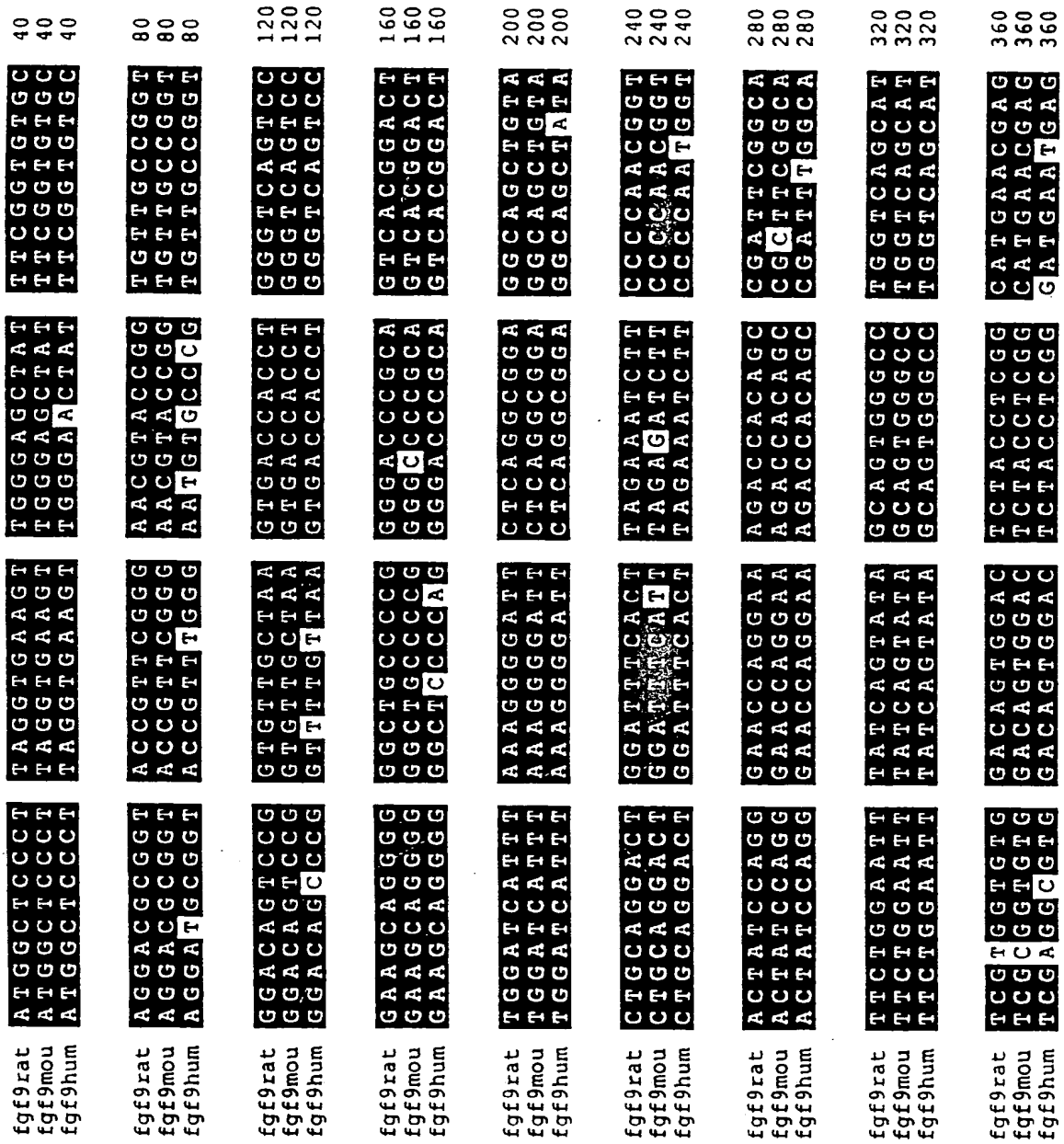

Fig. 3B

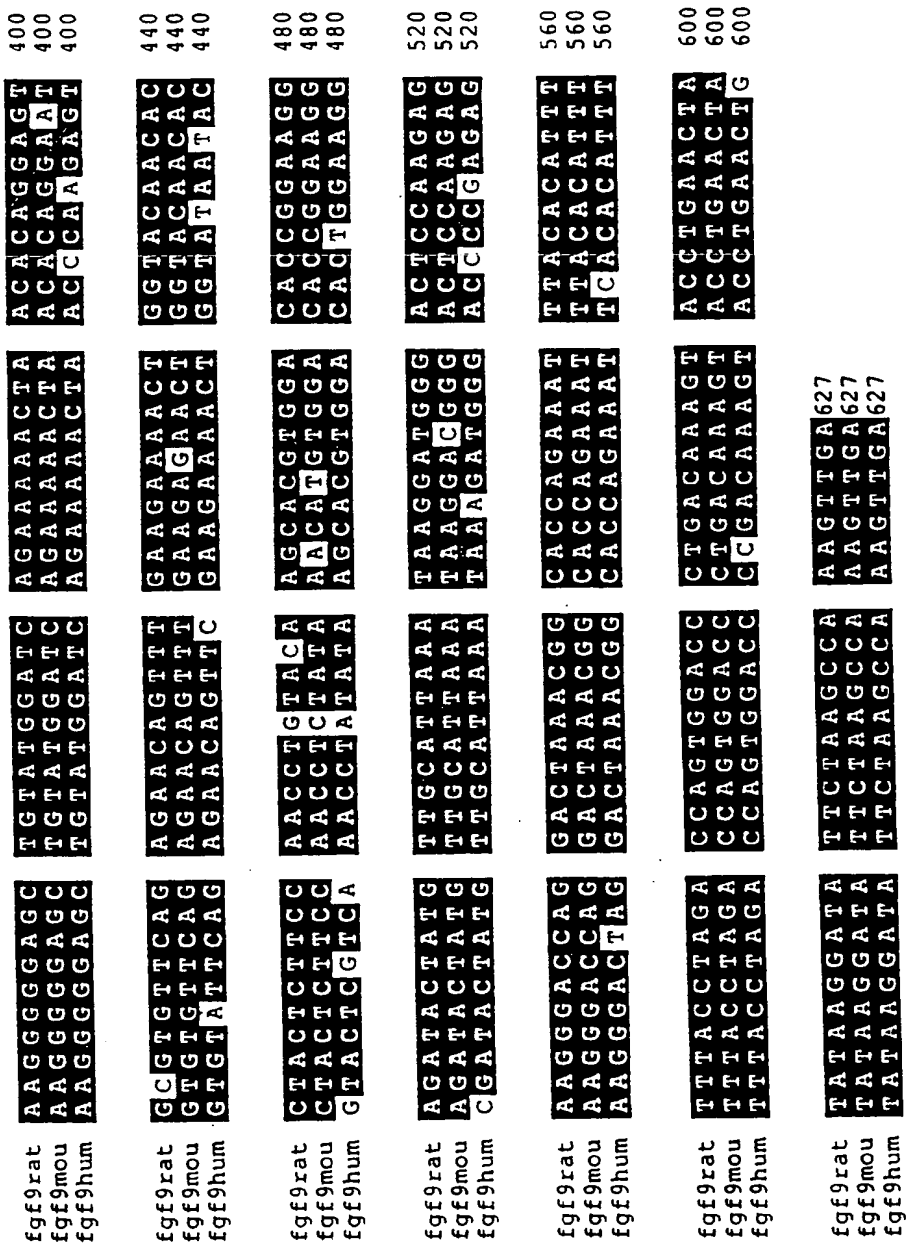

Fig. 3C

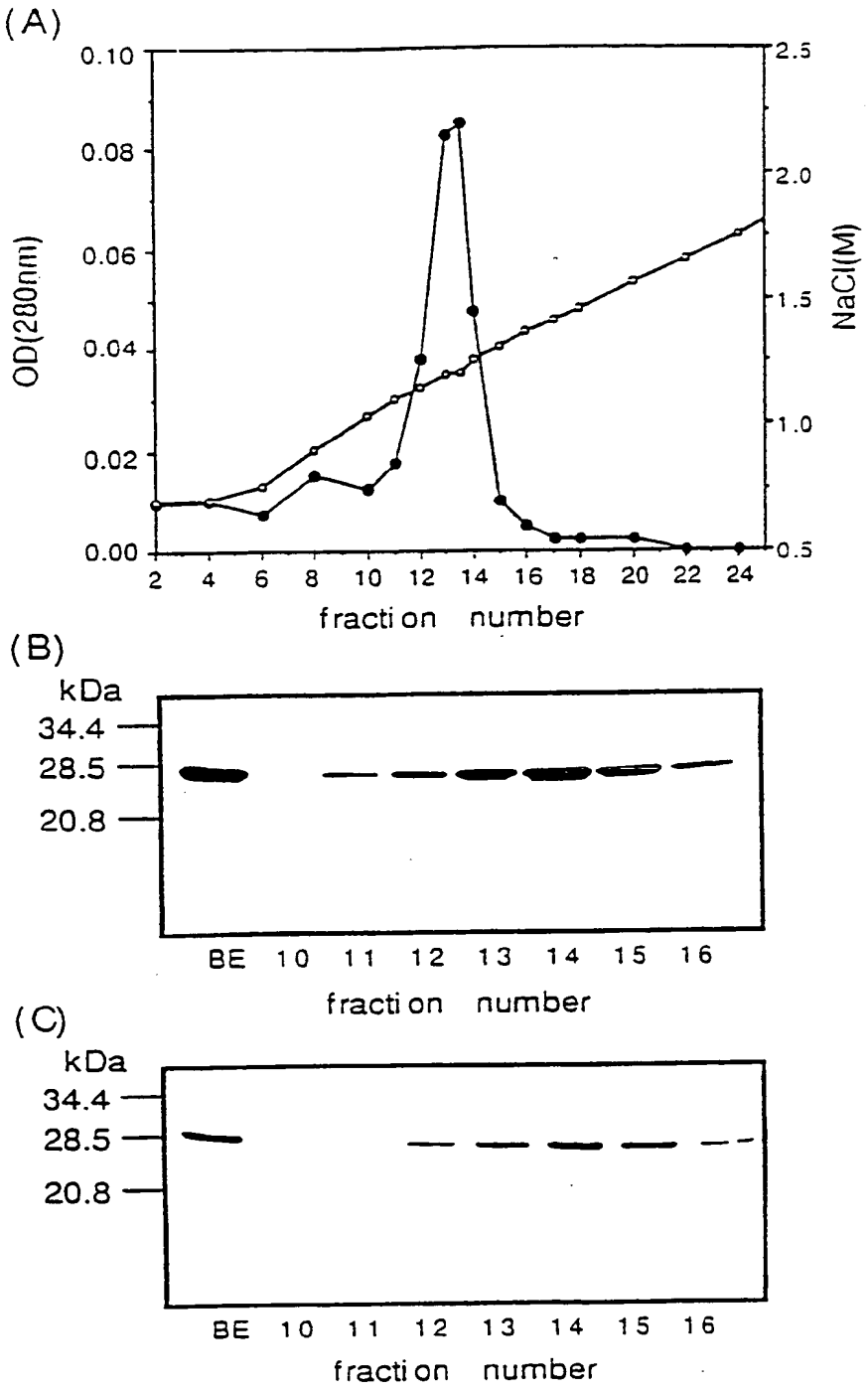

Fig. 4

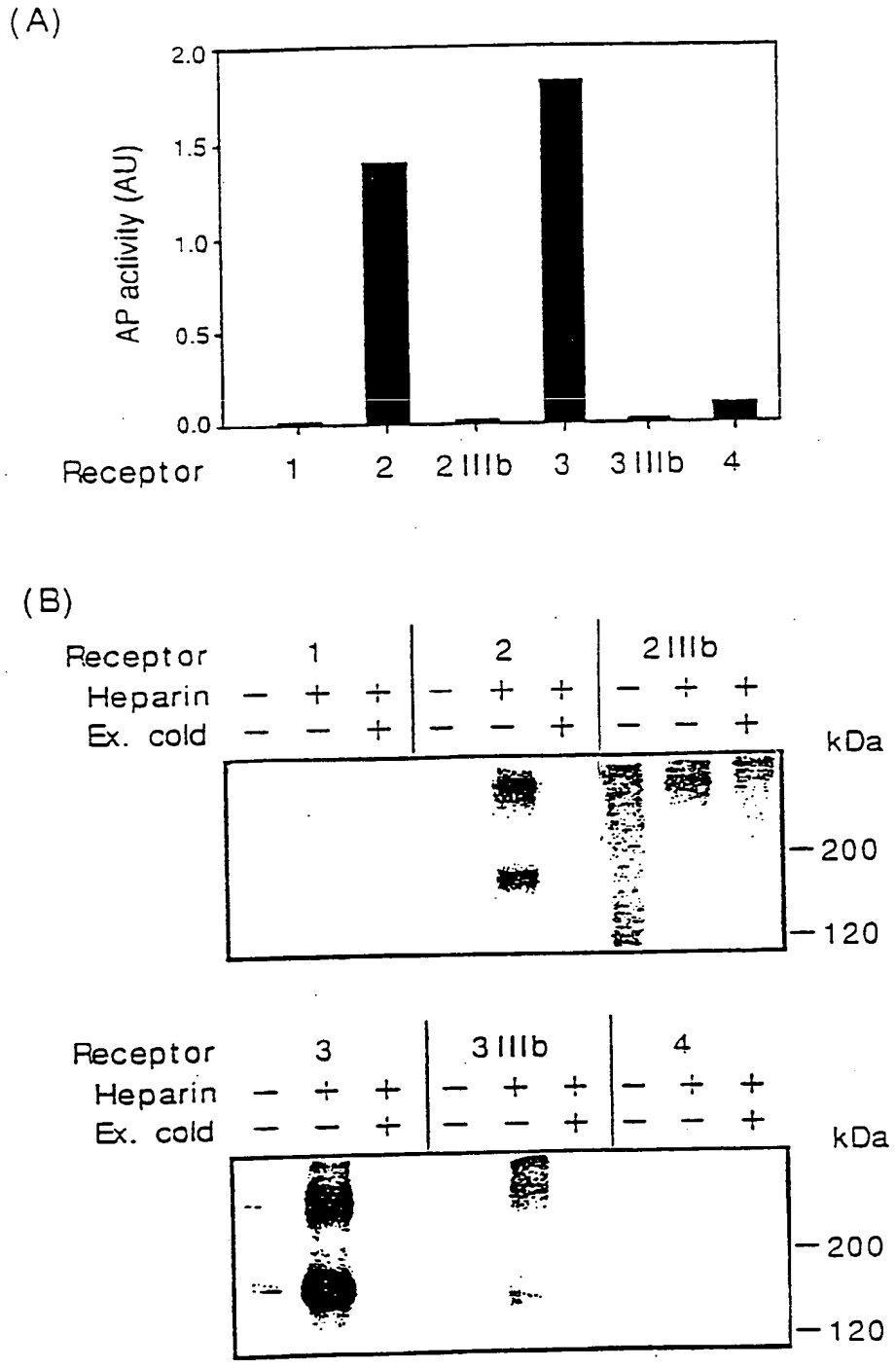

Fig. 5

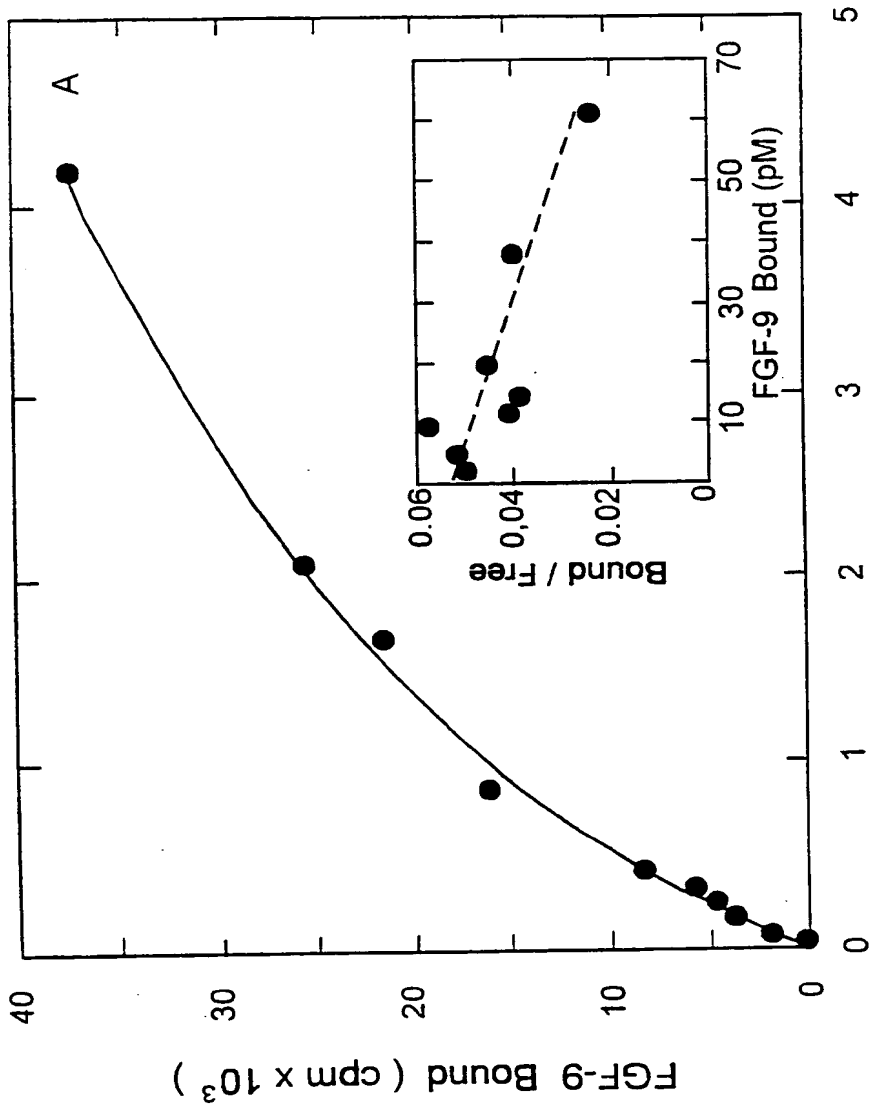

Fig. 6

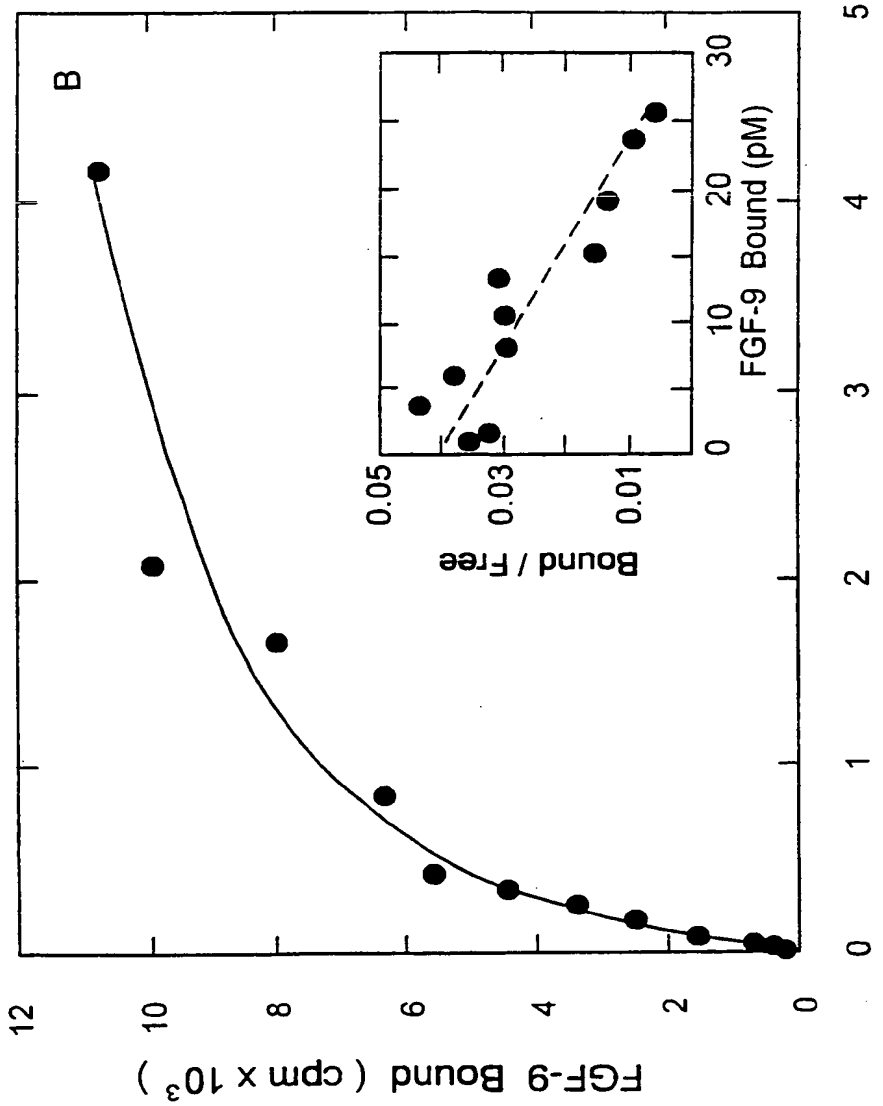

Fig. 6 (cont.)

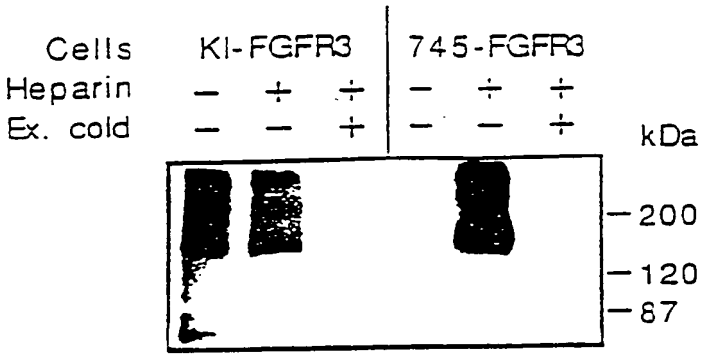

Fig. 7

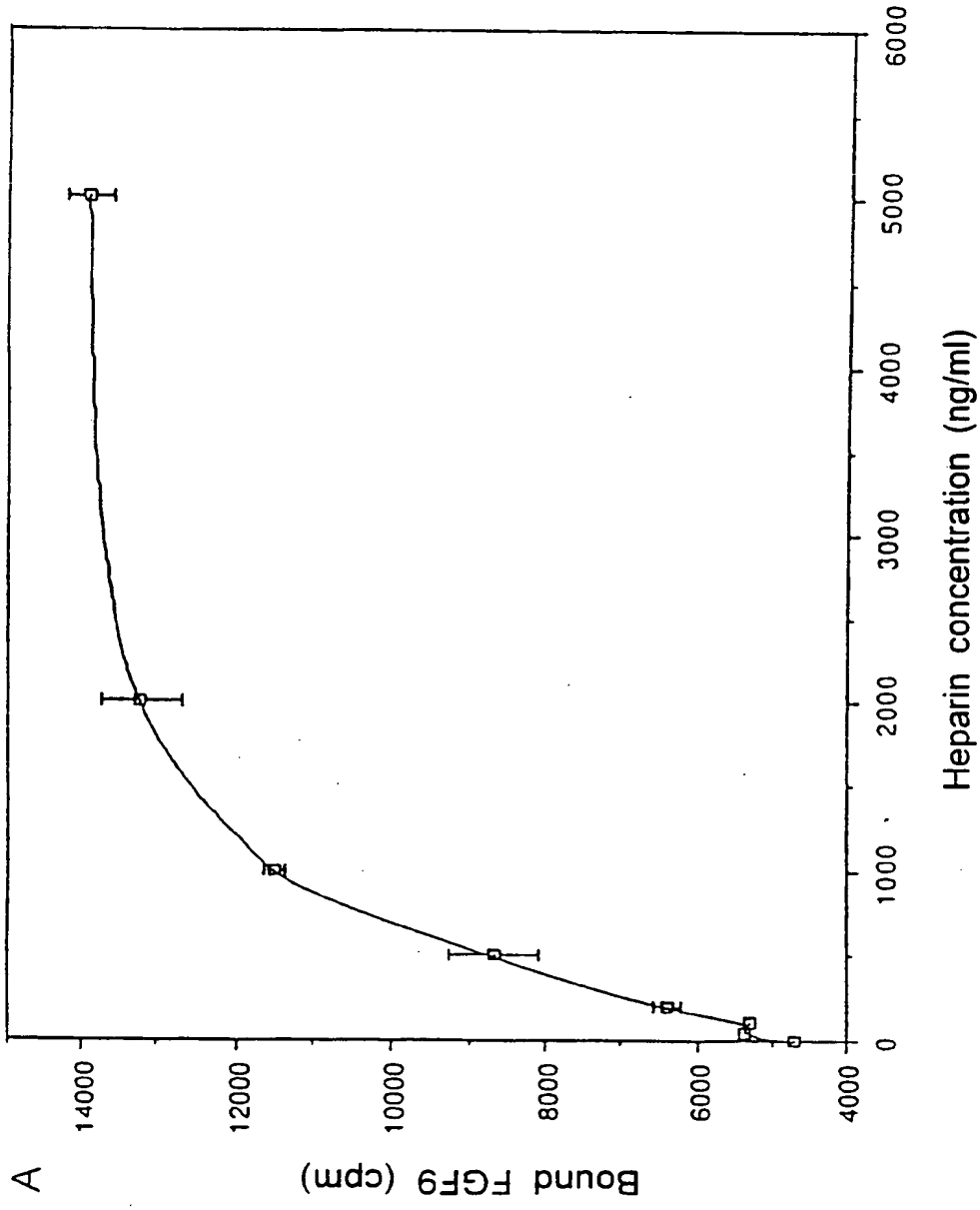

Fig. 8

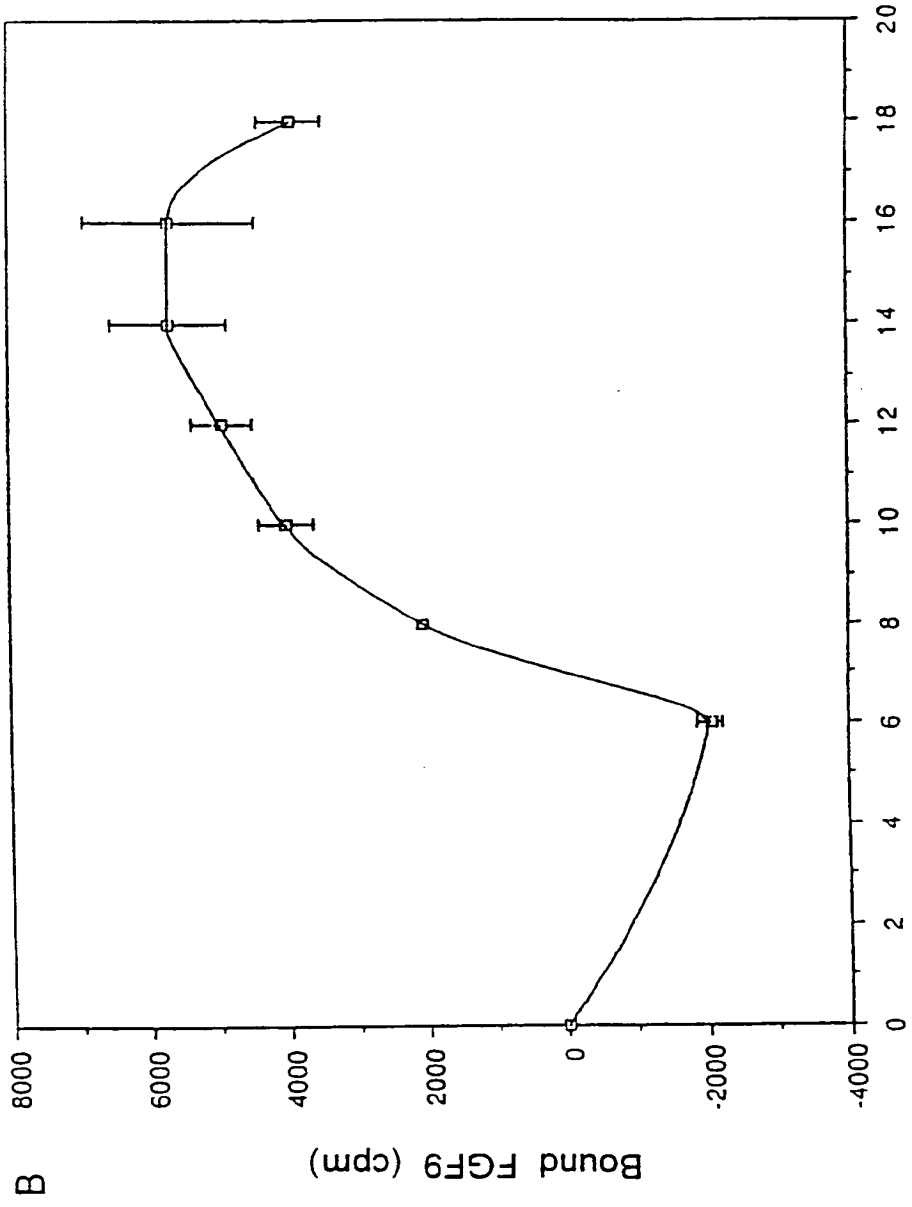

Fig. 8 (cont.)

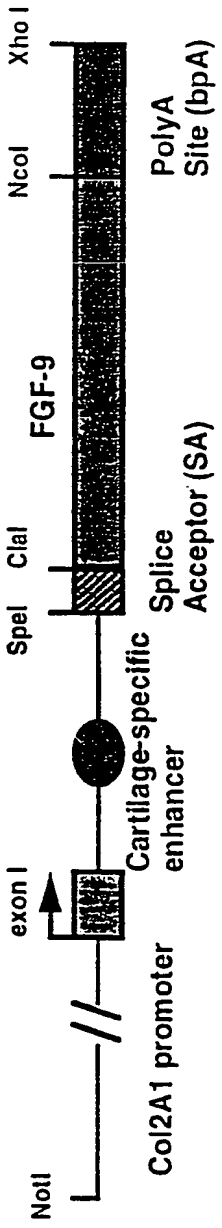

Fig. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IL96/00011

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :Please See Extra Sheet.
US CL :800/2; 435/7.1, 320.1; 424/198.1, 145.1; 530/350.1; 514/2
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 800/2; 435/7.1, 320.1; 424/198.1, 145.1; 530/350.1; 514/2

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPIDS APS MEDLINE BIOSIS CAPLUS EMBASE
search terms: FGF9, FGFR3, HBGF, mouse, avian, heparin, exostosis, hallux vagus, achondroplasia, chondromatosis, Yayon

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X, P	SANTOS-OCAMPO et al. Expression and Biological Activity of Mouse Fibroblast Growth Factor-9. Journal of Biological Chemistry. 19 January 1996, Vol. 271, No. 3, pages 1726-1731, especially page 1727 and paragraph bridging 1729-1730.	1-2
Y	US 5,270,197 A (YAYON ET AL.) 14 December 1993 (14.12.93), see entire document, especially column 2 lines 33-37.	1-2
X, E	US 5,571,895 A (KUROKAWA ET AL.) 05 November 1996 (05.11.96), see entire document, especially column 1.	17-19

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier document published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search
14 NOVEMBER 1996

Date of mailing of the international search report
22 NOV 1996

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